R&D of a PEM Fuel Cell, Hydrogen Reformer, and Vehicle Refueling Facility

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Las Vegas Hydrogen Fueling and Energy Station – Compression, Storage and Fueling

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Las Vegas Hydrogen Fueling and Energy Station – Distributed Hydrogen Generation and PEM Fuel Cell Power Generation

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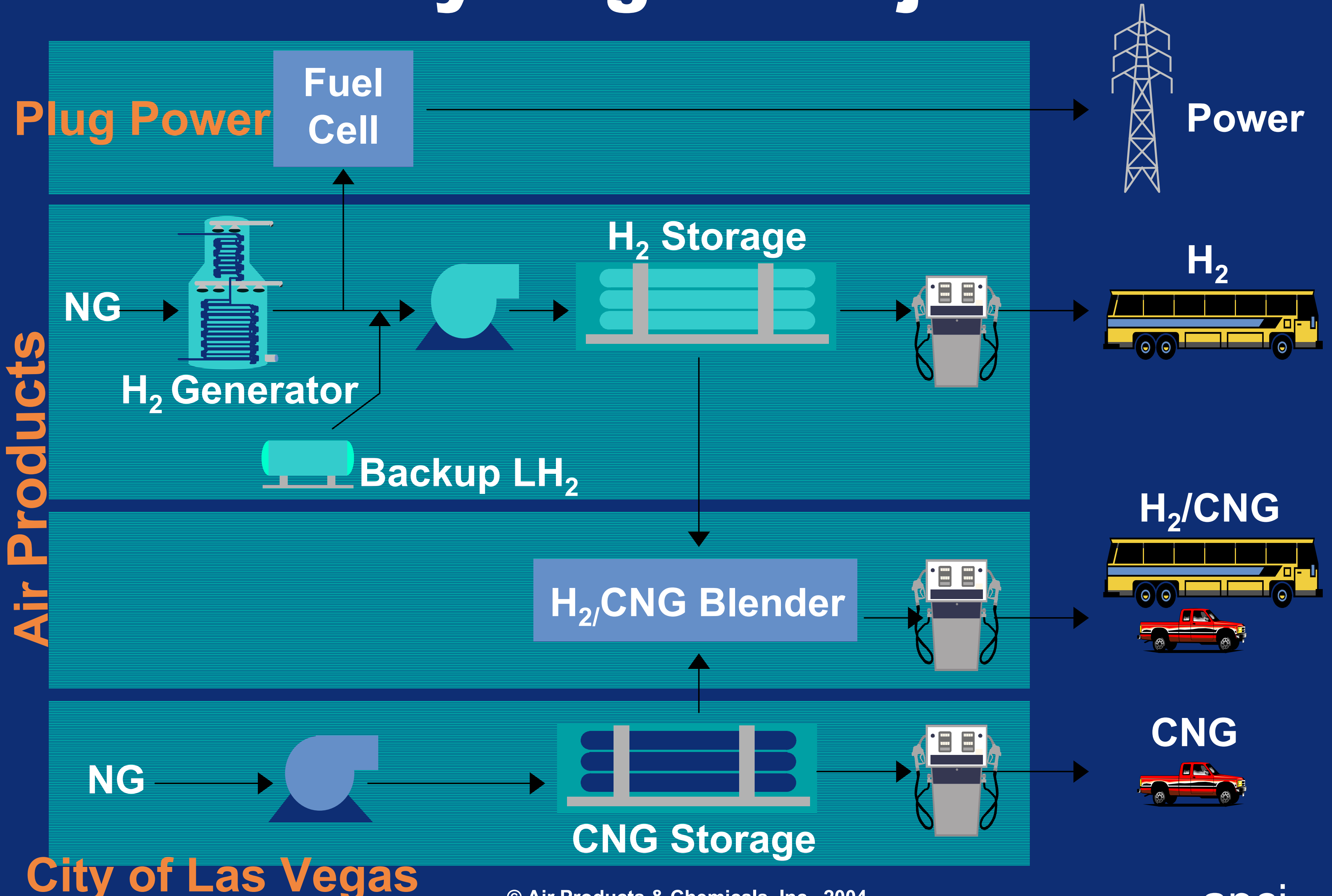
Nevada Hydrogen Project



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Program Objectives

- Demonstrate small, on-site H_2 production for fuel cell power generation and H_2 fueling station
- Demonstrate multipurpose vehicle refueling station to dispense H_2/CNG blend and pure H_2
- Demonstrate H_2-fueled stationary 50kW fuel cell
- Evaluate operability/reliability/economic feasibility, and certify integrated power generation and vehicle refueling designs
- Expand the current facility to serve as the first commercial facility when sufficient hydrogen demand develops.

FY03 Budget

- Total Project Budget:
  - $13,118,282
- Cost Sharing to Date:
  - DOE - $6,121,049
  - Air Products and Partners - $6,121,075
- FY2004 Funding
  - DOE - $360,000

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DOE Technical Barriers

DOE HFCIT Multi-Year Plan

- Technology Validation (Section 3.5.4.2), Task #3.
  - B. Storage – Cost, Performance, Structural Integrity
  - C. Hydrogen Refueling Infrastructure – Cost of Hydrogen, Low Availability, Safe Systems
  - D. Maintenance & Training Facilities – Operating and Maintenance Requirements, Personnel Training
  - E. Codes & Standards – Lack of Adopted Codes and Standards
  - I. Hydrogen and Electricity Co-production – Cost and Durability, Permitting, Safety Procedures

DOE Technical Targets

DOE HFCIT Multi-Year Plan

- Table 3.1.2 , Technical Targets
  - Reformer Efficiency, 2003, %(LHV) – 70%
    - Vegas Result, 2000 design – 68% (Current test data)
    - Test data collected while producing < 1 ppm CO purity
    - Vegas has capability to meet target; additional operation to demonstrate capability
    - PSU Program will deliver improvements to 2005 targets
  - Cost of Hydrogen, 2003, $/kg - $5.00
    - Vegas Result - < $5.00
    - Based on evaluation of Las Vegas Energy Station performance using HFCIT MYPP assumptions
    - PSU Program will deliver improvements to 2005 targets

Technical Approach

- Design, Build, Test
  - Scaled extension of research
  - Real-world performance and durability testing
  - Site selection, permitting, safety, operability, reliability, maintenance experience clarifies research and development gaps

- Severe Test Environment – Las Vegas
  - Desert climate – high summer temps, occasional freezing temps in winter
  - 2000 feet above sea level
  - CO2 Non-attainment (Clark County)

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Technical Approach

- Phase 1
  - Define System Requirements
  - Finalize System Definition to Requirements
  - System Engineering and Design
- Phase 2
  - Equipment Manufacturing
  - Detailed Design for Integrated System Installation
  - Installation, Commissioning and Start-up
- Phase 3
  - Demonstration Operation and Maintenance
  - Data Collection and Analysis
  - Feedback to Future Designs
  - Select Existing System Improvements

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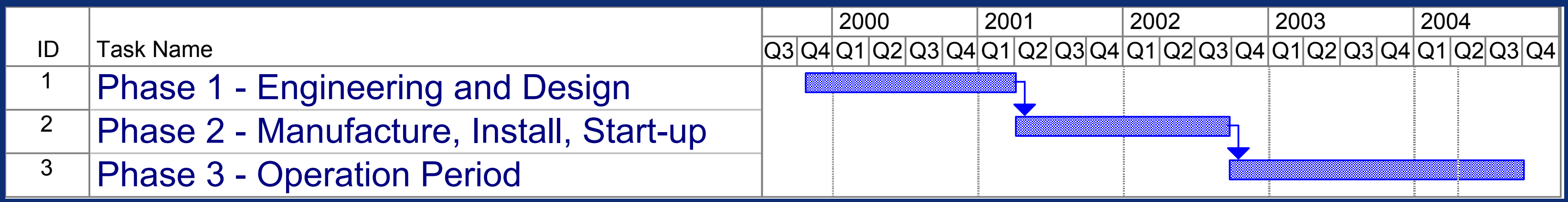
Project Timeline



- Hydrogen Generator Start-up at Site Achieved August 2002
- Site Opening Dedication in November 2002
- Currently 6 Quarters into the scheduled two year demonstration operating period

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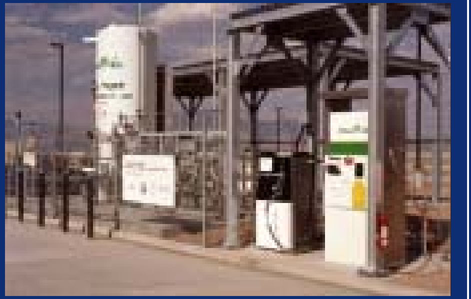
Project Safety

- **Safety Evaluated by DOE Safety Panel in Mar 04**
  - ➢ No major issues, some areas of interest:
    - Hydrogen fill rates
    - Underground piping
    - Mechanical joints
    - Pressurized Storage Vessel MIP



- **Site Safety Performance to Date Validates Design**
  - ➢ No safety incidents for site over 18 months of operation
  - ➢ 80+ fuel fills conducted without station incident
  - ➢ Inherently safe systems with safety instrumented controls
- **Vegas Energy Station Safety Efforts**
  - ➢ Hazop, MOC, Quantitative Risk as required
  - ➢ Use of applicable industry codes
  - ➢ Operational Readiness Inspection (ORI)
  - ➢ Trained Operating Personnel
  - ➢ Safety Performance Measured

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Technical Accomplishments – Hydrogen Generator

- **Status Overview**
  - Over 2800 hours operation
  - Satisfactory process operation and product purity capability
  - One button start, load following, additional features
  - Remote monitoring from Allentown / Sacramento
- **Performance**
  - 68% LHV Efficiency achieved w/ year 2000 design basis equipment , < 1 ppm CO purity control; 70% LHV Efficiency is achievable
  - Sound process technology implementation
  - Some reliability issues – common component issues
    - Burner failure
    - Spurious thermocouple signals
    - Compressor vibration issues
  - Interim inspection of equipment showed equipment in good mechanical condition

Technical Accomplishments – Hydrogen Generator (Cont)

- **Operating Experience Information**
  - Severe diurnal cycling affects ambient conditions, influencing process dynamics
  - Seasonal ambient changes influence process dynamics
  - Steam system dynamics and control
  - More than sufficient instrumentation for safe and reliable control system, but always one or two other data points you could use
  - Shutdown / Start-up thermal cycling potential longer term durability issue for catalyst
- **Next Operating Test Campaign**
  - Added primary air flow measurement
  - Added steam flow measurement
  - Added additional thermocouples along reformer tube to monitor thermal stratification
  - 2000 hour on-purpose test run in progress

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Technical Accomplishments –
Fueling Station (Cont)

- **Status Overview**
  - Approx. 70 H2 / CNG Fills
  - Approx. 10 H2 Fills
  - Fleet not yet established
    - One H2/CNG LDV (F150 Pick-up)
    - One H2/CNG Bus

- **Performance**
  - Storage systems providing adequate capacity for current demand
  - Dispenser engineering and design validated (2000 design basis, non-communication fill)
  - Instrument air has been primary cause of isolated issues

City of Las Vegas H2 / CNG Bus

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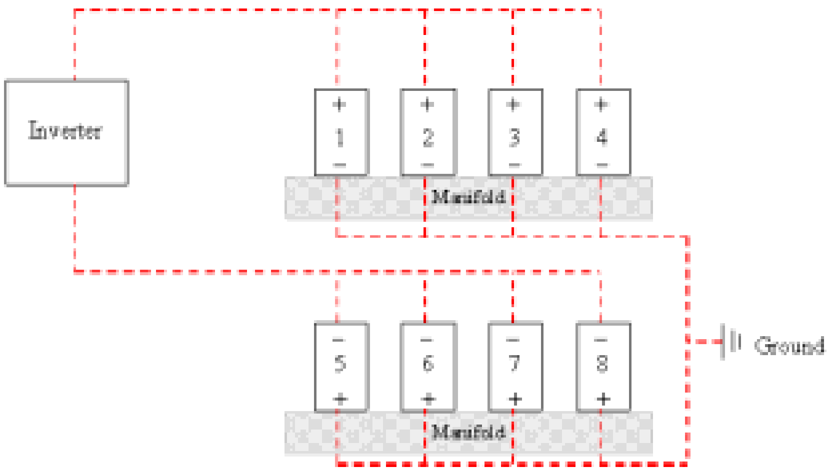
Project Overview

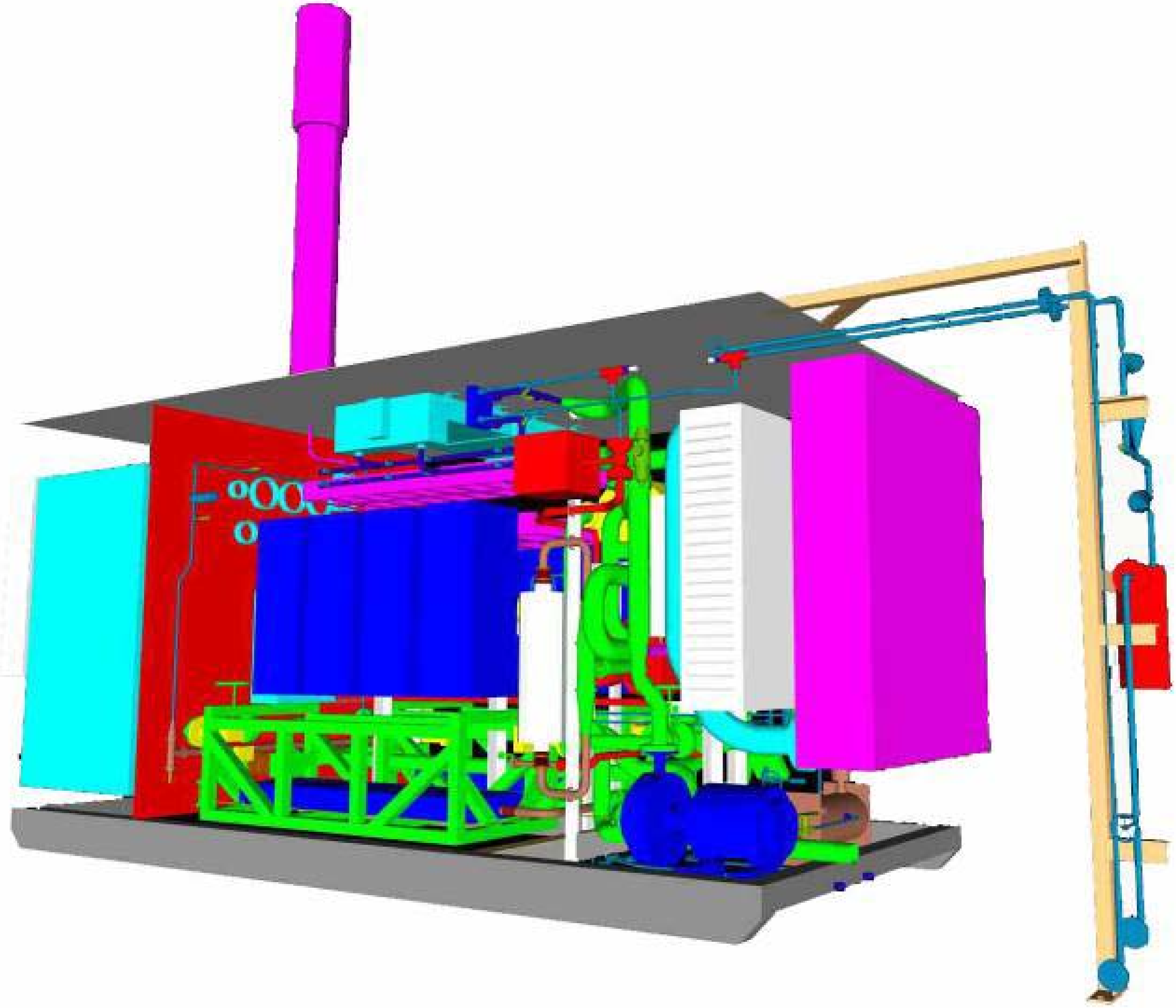
- Completed Fuel Cell system detailed design, fabrication, and testing.
  - •Plug Power's first large scale stationary system.
- Initial startup and qualification testing yielded a number of design changes related to component selection, control and electronic equipment, software algorithms, and gas delivery systems.
- Executed test program to first qualify individual subsystems followed by final system configuration testing.
- Test data provided an operational baseline and validation of the interface conditions to support integration into the refueling station.
- Shipped 50 kW fuel cell system to Las Vegas - October 2001.
- System commissioned September 2002.

Overview & Equipment



Parameter	Specification
Installation Location	Outdoor
Grid Parallel	Yes
Power Output/Set points (approximate)	15kW, 30 kW, 50 kW
Remote monitoring capability	Via phone line and modem
Electrical Output	480 VAC, 3 Phase, 60 Hz
Power Quality	IEEE 519 or better
Ambient Design Conditions	Minimum Temperature: 10 °F Maximum Temperature: 115 °F
Fuel Supply Purity Operating Supply Pressure Maximum Design Pressure H2 Supply Temperature	Hydrogen 98 % to 99.9 % < 100 ppm hydrocarbons <1 ppm carbon monoxide <1 ppm sulfur 100 +/- 10 psig 150 psig -30ºF to 140ºF

Overview & Equipment



Key Technical Barriers *

❖ Cost of Electricity (COE)

- Plug Power utilizes a COE approach to assess in order of importance, elements of fuel cell operations on the pathway to commercial viability. The COE model has three elements.

- **Capital or First Cost**
  - O. Stack Material & Manufacturing Costs
- **Operating and Maintenance Cost**
  - E. Durability
  - R. Thermal & Water Management
- **Energy Conversion Efficiency**
  - F. Heat Utilization
  - G. Power Electronics

*** as identified in the Multi-Year Research, Development, and Demonstration Plan Section 3.4.4.2 – Barriers**

plugpower FUEL CELL SYSTEMS

Technical Barriers

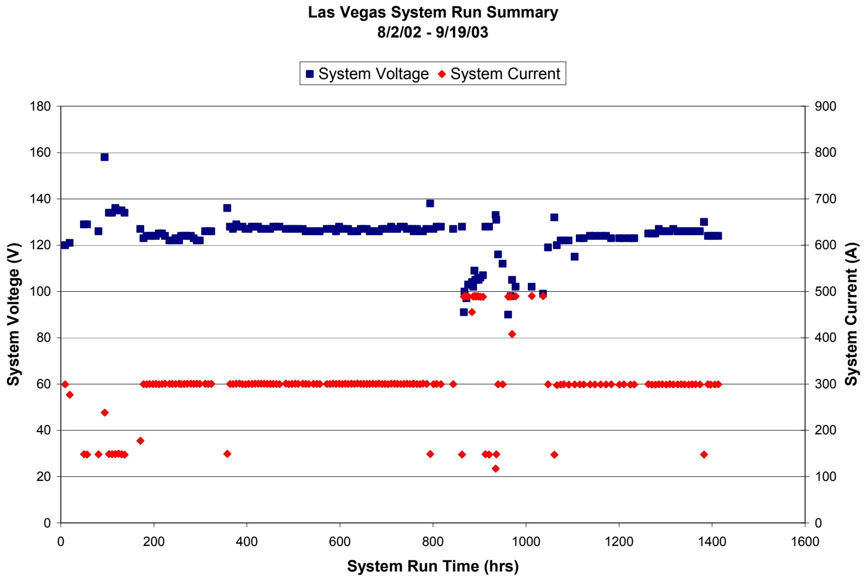
- ❖ Fuel Cell System
  - Approach changed from single stack to eight manifolded stacks
  - Limited experience in manifolding stacks, cell voltage scanners
  - Balance of plant issues included cathode humidification
  - Overall control system utilized Lab View - lacked robustness and ability to easily change software as changes were identified
  - Limited lifetime of this generation of stack materials (200 hours in 2001 to >8000 hours today)
  - Electrical integration and control of stacks required development of new approaches
  - Viability of system design deemed not able to be made commercially viable. First cost of $6000 per kW too high for marketplace
- ❖ Site Integration
  - Initial experience in connecting fuel cell to third-party reformer
  - Grid interconnection initially challenging (approvals)

Technical and Program Accomplishments

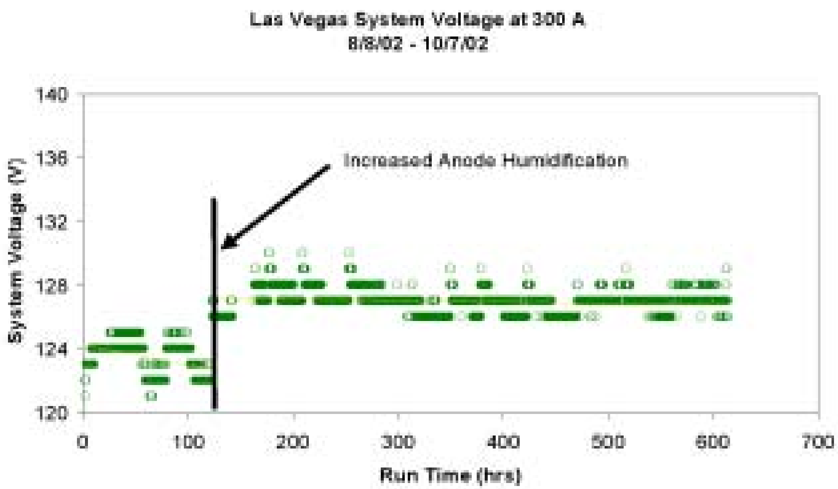
- Fuel Cell System Design
  - Cell voltage monitoring critical to reliability
  - Ability to leverage existing design (Platform approach)
  - System integration experience
  - Key learning of electrical noise issues, resolutions
  - Manifolding stacks
  - Three Phase Inverter integration
  - Basic understanding of stack humidification & water management

- Site Integration
  - Fuel cell system – Reformer integration.
  - Hydrogen design requirements

Technical and Program Accomplishments

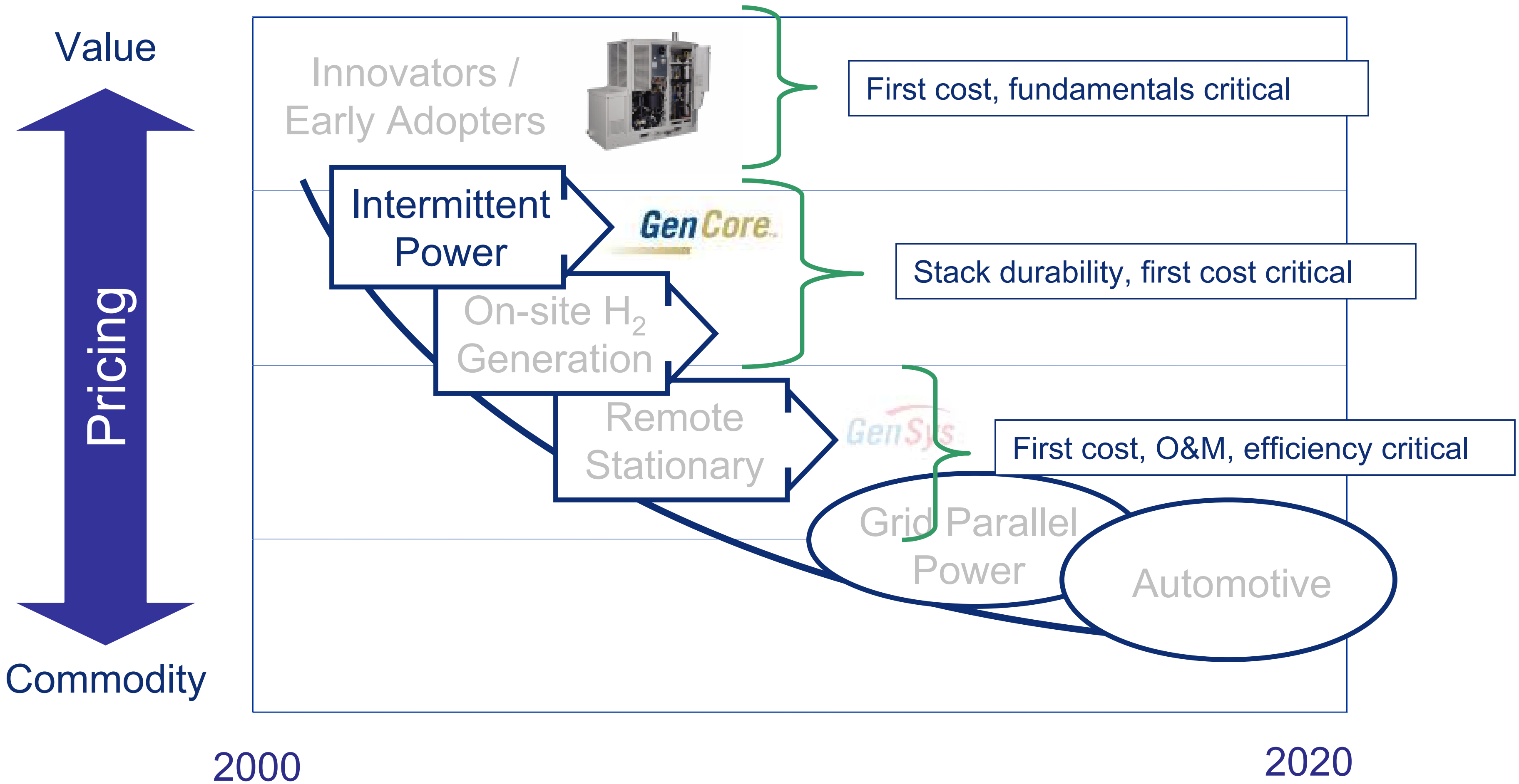


System Run Time: 1414 hours
Power Produced: 43,500 kWh
System Efficiency: 36.3%
Stack Efficiency: 46.8%



Impact of humidification change
Cell degradation rate decreased to 5μV, translating to projected stack life of 12,000 hours.

Adoption (as a function of Technical Barriers)



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Responses to Prior Year Comments

- Data Collection, Analysis and Econ Evaluation
  - Interim evaluations concluded and reports in process
  - Data exchange with collaborating entities underway
  - Additional data collection and evaluation to follow
- Site Footprint (relatively large footprint)
  - Energy Station site took advantage of available plot
  - Additional unoccupied foundation is part of site
  - Other Air Products sites are much smaller
  - PSU site will be much smaller
- Educational Benefits
  - Significant international and national visitor traffic
  - International Energy Agency
  - DOE Safety Panel
  - Numerous conference tours (PowerGen, APTA, etc.)
  - Permit experiences shared

Future Work

- Conclude current operating period
  - Collect operating data for analysis
    - Addl Generator analysis for added data pts
    - Addl economic evaluation
    - Incorporation of lessons learned into PSU
      - H2 Generator Packaging
      - H2 Generator Process and Control Improvements
      - System Design, Costs and Economics
  - Support CLV fleet expansion
- Planning for continued DOE support of site beyond current operating period
  - Potential for upgrade of fueling systems for 350 Bar / 5000 psig fueling (systems mechanically rated for 5000 psig)
  - Potential for upgrade of fueling systems for communication based fill
  - Continued use of Vegas asset as a R&D test bed facility
  - Support Vegas Fleet Build-out
    - Current fleet of 268 CNG vehicles
    - Progressive in testing / adopting alternative fuels

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Collaborations

- Special Thanks to Dr. Venki Raman, Air Products
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- Dan Hyde, City of Las Vegas Fleet Site Mgr
- Plug Power – Rob Dross, Dave Parry, Bob Sinuc, Scott Wilshire
- Sandia National Laboratory – Andrew Lutz
- International Energy Agency
- DOE Safety Panel

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Thank you

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